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Primordial Anti-Biasing & Galaxy Infall Kinematics

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Part I

The Effect of Primordial Anti-Biasing on the Local Measurements of the Key Cosmological Parameters

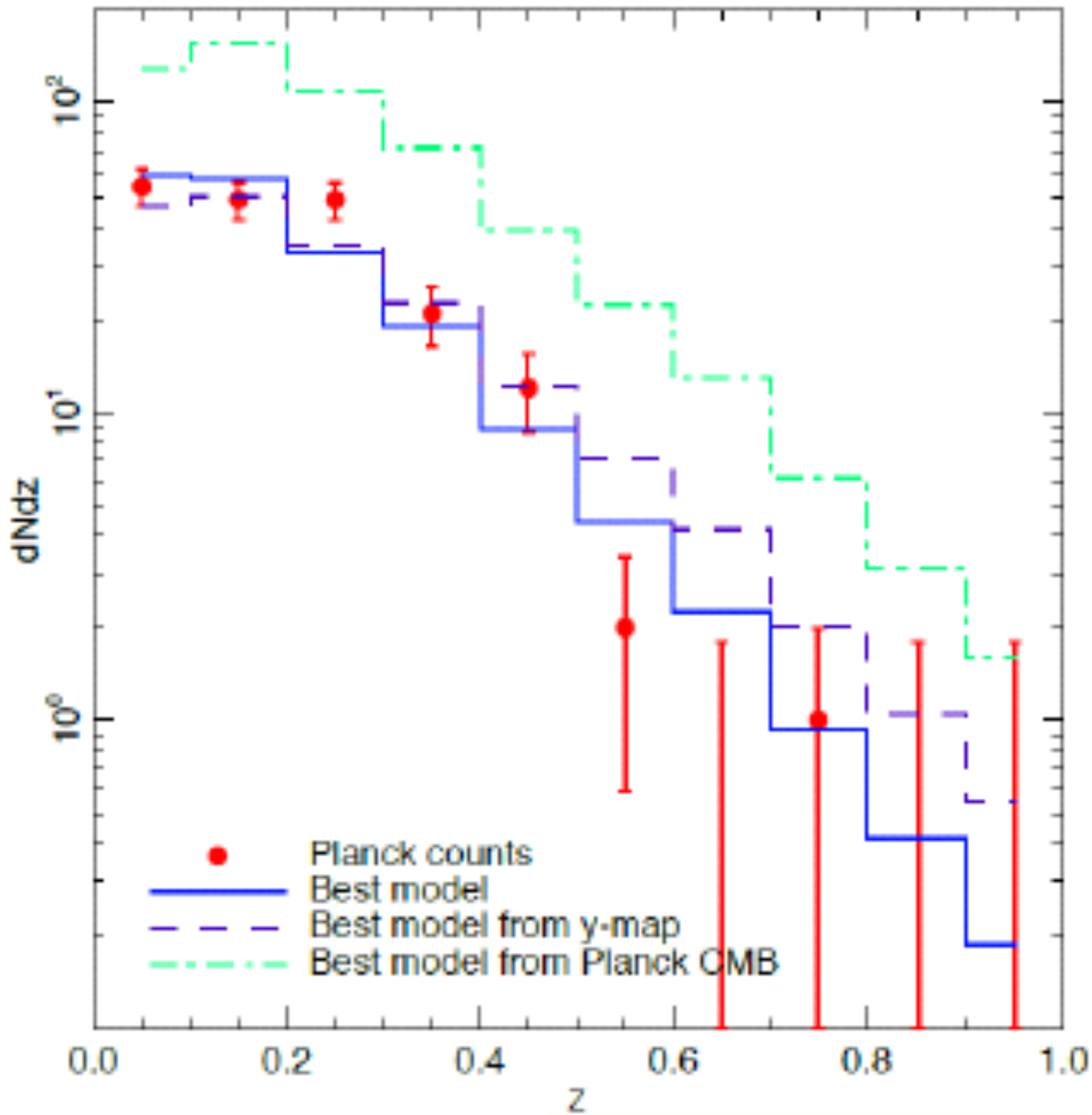
Lee 2014, MNRAS, 440,119

Introduction

- To complete the simplest flat ΛCDM picture, it requires
  - precise determination of its key cosmological parameters
  - consistency between the local and the CMB measurements

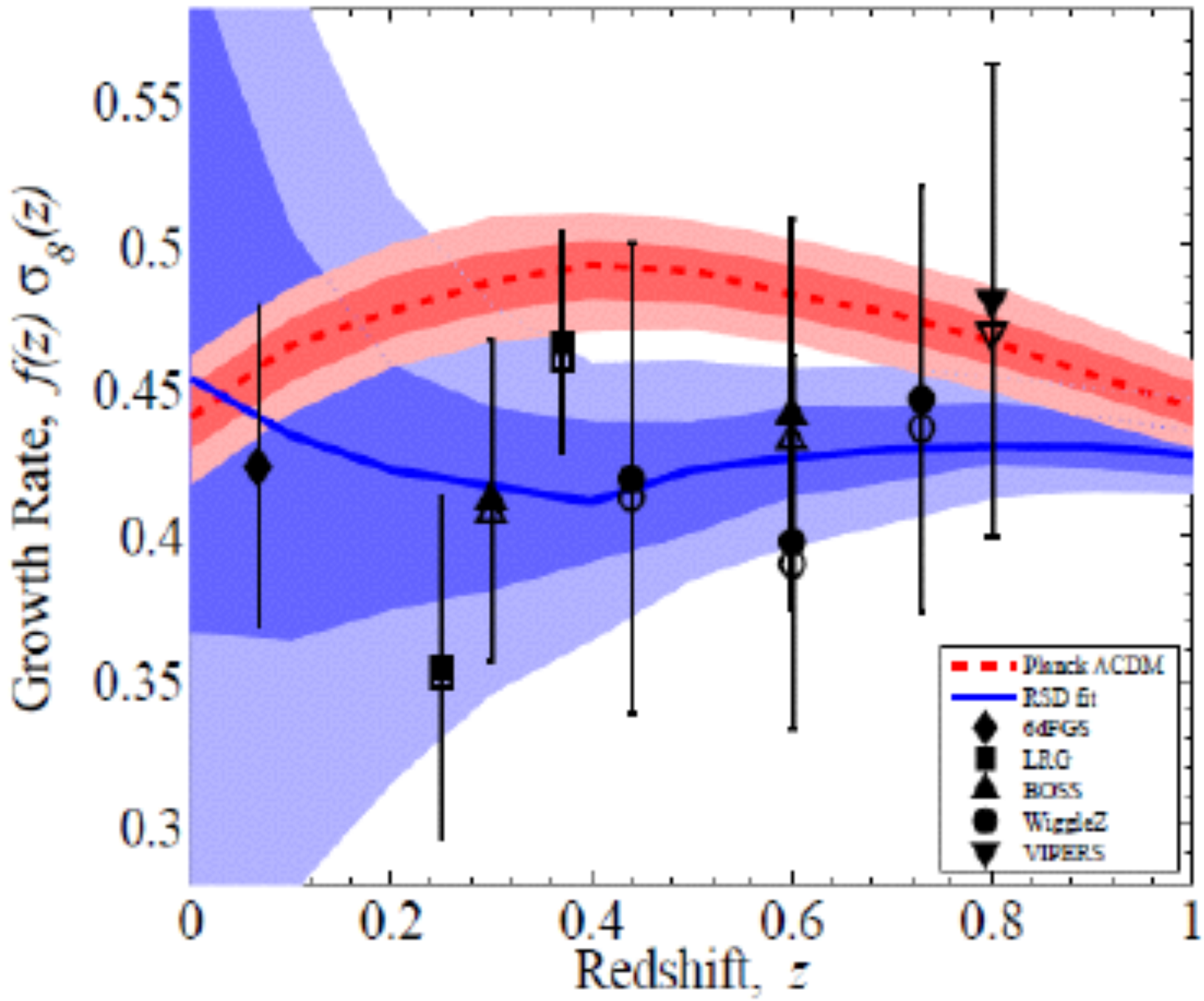
Inconsistency between Local and Distant

- The local universe seems to expand more rapidly than expected from Planck.
- There are less numbers of the galaxy clusters in the local universe than expected from the Planck cosmology.
- The number counts of massive clusters evolve less rapidly than expected from the Planck cosmology



Planck 2013 results XX, arXiv:1303.5080

$$f \equiv \frac{d \ln D}{d \ln a}$$



Macaulay et al. 2013, PRL, 111,161301

Distant vs. Local

- From the Planck CMB analysis (Planck 2013 results XVI)

$$\Omega_m = 0.314 \pm 0.020, \ \sigma_8 = 0.834 \pm 0.027$$

- From the evolution of the number counts of the SZ clusters (Planck 2013 results XX)

$$\Omega_m = 0.29 \pm 0.02, \ \sigma_8 = 0.77 \pm 0.02$$

- From the mass function of the low-z clusters (Vikhlinin et al. 2009)

$$\Omega_m = 0.255 \pm 0.043, \ \sigma_8 = 0.805 \pm 0.011$$

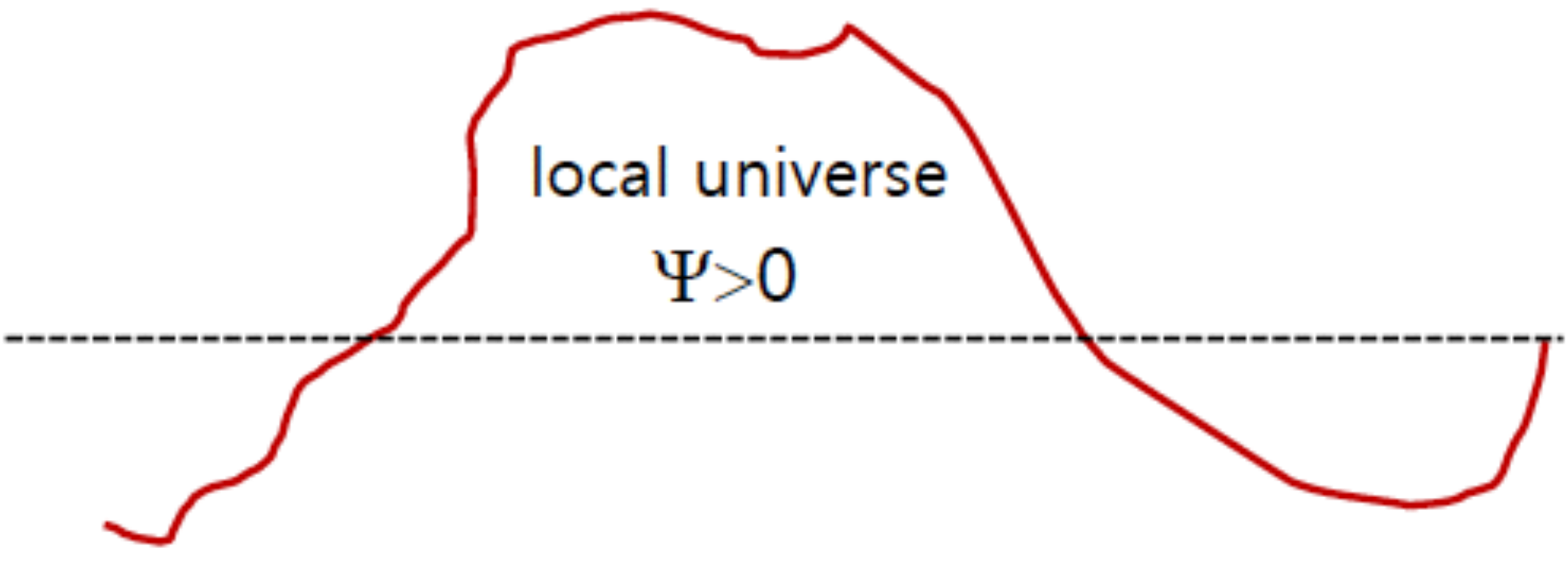
Previously Suggested Solutions

- The data might be wrong
  - unknown systematics must exist

- The model hast to be improved by taking into account:
  - massive neutrinos (Wyman et al. 2013)
  - coupled dark energy model (Salvatelli et al. 2013)
  - inhomogeneous geometry (e.g., Fluery et al. 2013)

A New Approach

- The local universe formed in the crest of the primordial peculiar potential field (Ψ)



Primordial Potential

- Related to the linear density field as

$$\delta \propto \nabla^2 \Psi$$

  - much smoother than the linear density field
- The nonlinear potential field resembles the smoothed version of the primordial potential (e.g., Pauls & Melott 1995)
- The characteristic scale:

$$R_\varphi = \sqrt{3}\sigma_\varphi/\sigma_{\varphi'} = \sqrt{3\,\frac{\int_{k_l}^{\infty} dk k^{-2} P(k)}{\int_0^{\infty} dk P(k)}} \approx 120\ h^{-1}\ \mathrm{Mpc}$$

The Press-Schechter Theory

$$\frac{dN}{dM} = 2\frac{\bar{\rho}}{M}\left|\frac{dF(\delta_c,\ M)}{dM}\right| ,$$

$$F(\delta_c; M) = \int_{\delta_c}^{\infty} d\delta\, p(\delta; \sigma_\delta) ,$$

$$\sigma_\delta^2(M) = \int_0^{\infty} dk\, k^2 P_\delta(k) W^2(k; M) ,$$

Modification of the PS Formalism

$$F(\delta_c; M|\psi > 0) = \int_{\delta_c}^{\infty} d\delta\, p(\delta; \sigma_\delta, \sigma_c, \sigma_\psi|\psi > 0) \ ,$$

$$p(\delta, \sigma_\delta, \sigma_c, \sigma_\psi|\psi > 0) = \frac{\int_0^\infty d\psi\, p(\delta, \psi; \sigma_\delta, \sigma_c, \sigma_\psi)}{\int_0^\infty d\psi\, p(\psi; \sigma_\psi)} = 2\int_0^\infty d\psi\, p(\delta, \psi; \sigma_\delta, \sigma_c, \sigma_\psi) \ ;$$

$$p(\delta, \psi; \sigma_\delta, \sigma_c, \sigma_\psi) = \frac{1}{[(2\pi)^2\sigma_\delta^2(\sigma_\psi^2 - \sigma_c^4/\sigma_\delta^2)]^{1/2}} \exp\left(-\frac{\delta^2}{2\sigma_\delta^2}\right) \exp\left[-\frac{(\psi + \sigma_c^2\delta/\sigma_\delta^2)^2}{2(\sigma_\psi^2 - \sigma_c^4/\sigma_\delta^2)}\right] \ .$$

$$\sigma_c^2(M) = \int_0^\infty dk\, P_\delta(k) W(k; M) \ .$$

$$\sigma_\psi^2 = \int_{k_{\rm nl}}^\infty dk\, k^{-2} P_\delta(k) \ ,$$

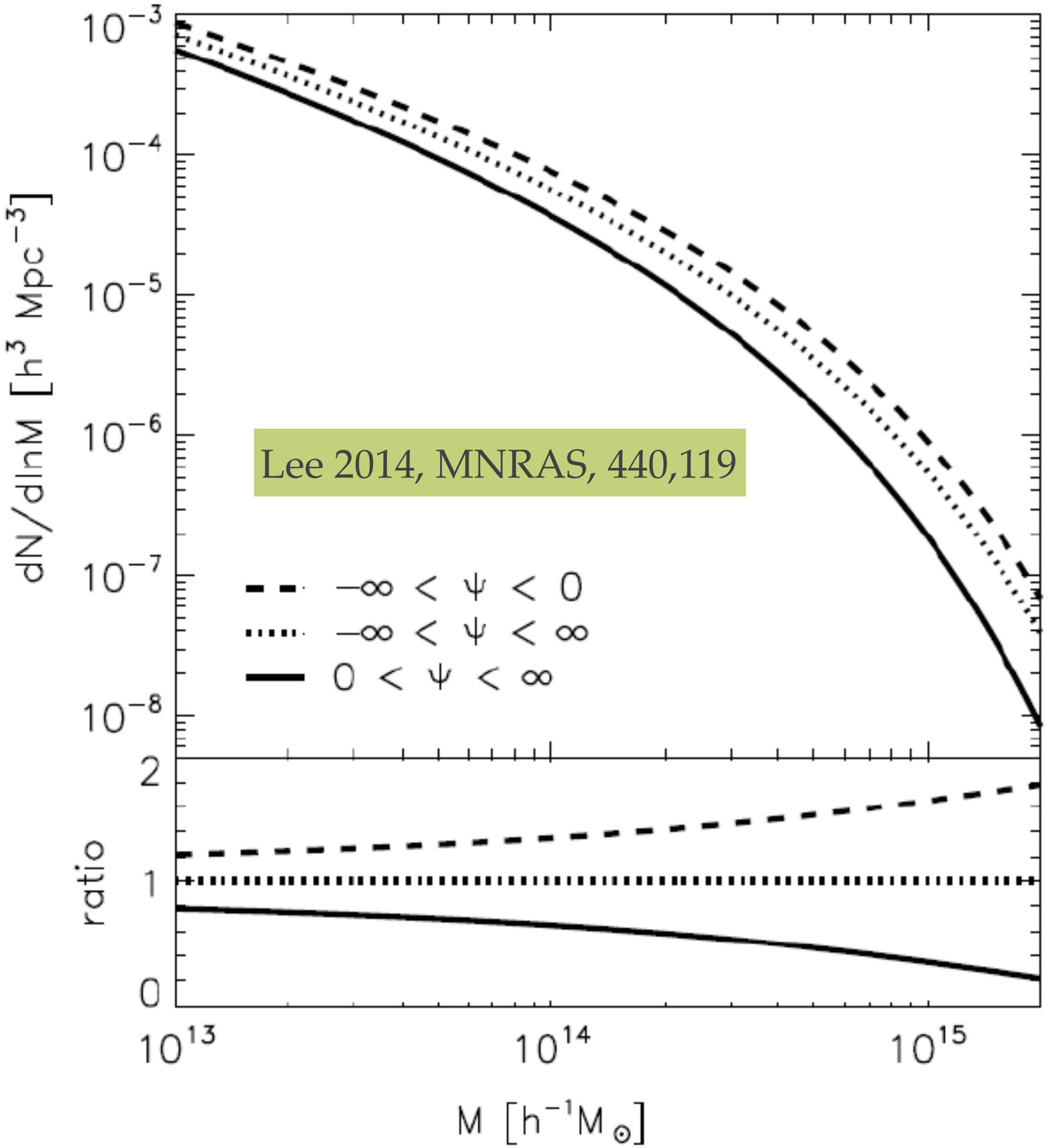
$$\nu \equiv \frac{\delta}{\sigma}\,, \qquad \mu \equiv \frac{(\psi + \sigma_c^2 \delta/\sigma_\delta^2)^2}{2(\sigma_\psi^2 - \sigma_c^4/\sigma_\delta^2)}\,.$$

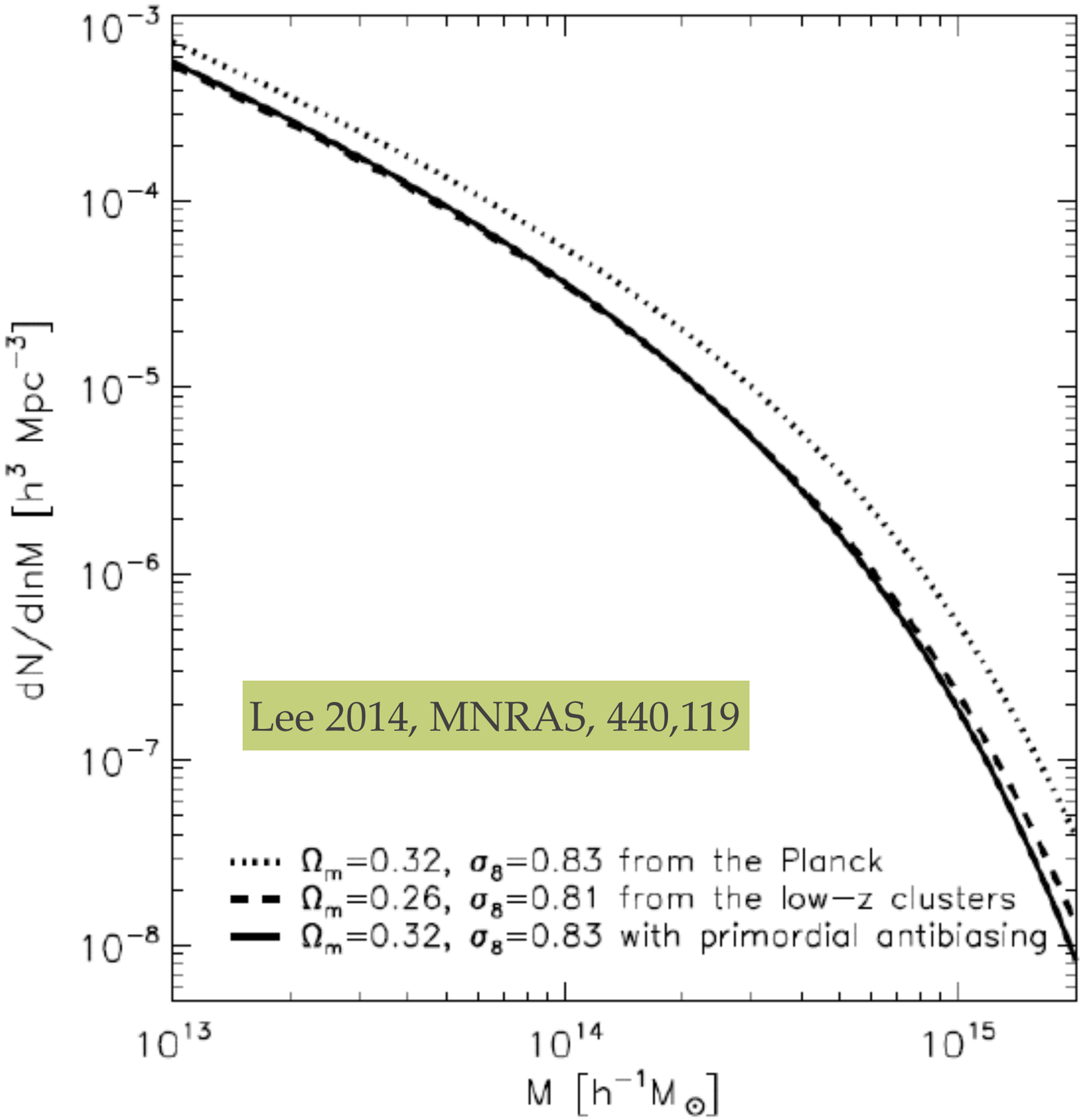
$$p(\nu,\mu)d\nu\, d\mu = \frac{1}{(2\pi)^{1/2}} \exp\left(-\frac{\nu^2}{2}\right) \frac{1}{(2\pi)^{1/2}} \exp\left(-\frac{\mu^2}{2}\right)$$

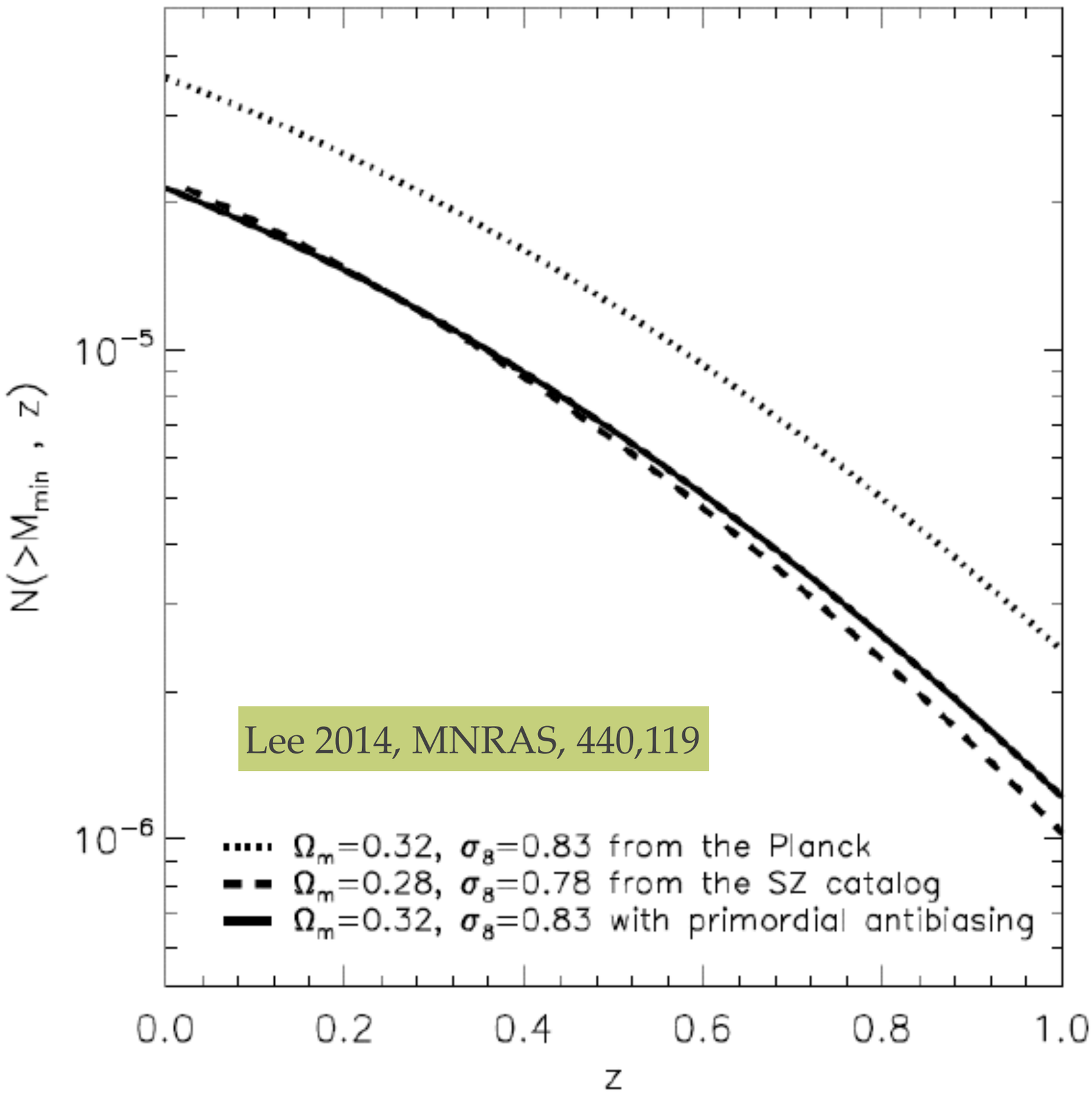
$$F(M;\nu_c,\mu_c) = \int_{\nu_c}^{\infty} d\nu \frac{1}{(2\pi)^{1/2}} \exp\left(-\frac{\nu^2}{2}\right) \int_{\mu_c}^{\infty} d\nu \frac{1}{(2\pi)^{1/2}} \exp\left(-\frac{\mu^2}{2}\right)$$

$$\frac{dN}{dM} = 4\frac{\bar{\rho}}{M}\left|\frac{dF}{dM}\right| = 4\frac{\bar{\rho}}{M}\left|\frac{d\nu_c}{dM}\frac{dF}{d\nu_c} + \frac{d\mu_c}{dM}\frac{dF}{d\mu_c}\right|$$

$$\begin{aligned}
\frac{dF}{d\nu_c} &= \frac{1}{(2\pi)^{1/2}}\exp\left(-\frac{\nu^2}{2}\right)\left[\frac{1}{2}\mathrm{erfc}\left(\frac{\nu_c}{2}\right)\right] , \\
\frac{dF}{d\mu_c} &= \frac{1}{(2\pi)^{1/2}}\exp\left(-\frac{\mu^2}{2}\right)\left[\frac{1}{2}\mathrm{erfc}\left(\frac{\mu_c}{2}\right)\right] , \\
\frac{d\nu_c}{dM} &= \frac{d\nu_c}{d\sigma_\delta}\frac{d\sigma_\delta}{dM} , \\
\frac{d\mu_c}{dM} &= \frac{d\mu_c}{d\sigma_\delta}\frac{d\sigma_\delta}{dM} + \frac{d\mu_c}{d\sigma_c}\frac{d\sigma_c}{dM} .
\end{aligned}$$


Lee 2014, MNRAS, 440,119
$-\infty < \psi < 0$
$-\infty < \psi < \infty$
$0 < \psi < \infty$
dN/dlnM [h^3 Mpc^{-3}]
ratio
M [$h^{-1}M_\odot$]
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
2
1
0
10^{13}
10^{14}
10^{15}


Lee 2014, MNRAS, 440,119
Ω_m=0.32, σ_8=0.83 from the Planck
Ω_m=0.26, σ_8=0.81 from the low−z clusters
Ω_m=0.32, σ_8=0.83 with primordial antibiasing
dN/dlnM [h^3 Mpc^{-3}]
M [$h^{-1}M_\odot$]
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{13}
10^{14}
10^{15}



Lee 2014, MNRAS, 440,119

Summary and Future Works

- The inconsistency between the local and the distant measurements of Ω_m and σ_8 can be explained away in the ΛCDM model if the local universe is assumed to have formed in the primordial potential crest.
- The characteristic scale of the primordial potential crest has to be empirically determined.
- To investigate the effect of primordial anti-biasing on the linear growth rate, halo merging rate, halo assembly bias and galaxy down-sizing phenomenon.

Part II

Galaxy Infall Kinematics around the Virgo Cluster as a Cosmological Probe

Lee, Rey & Kim, 2014a, arXiv: 1406.5250

Lee, Rey & Kim, 2014b, in preparation

Galaxy Infall Kinematics

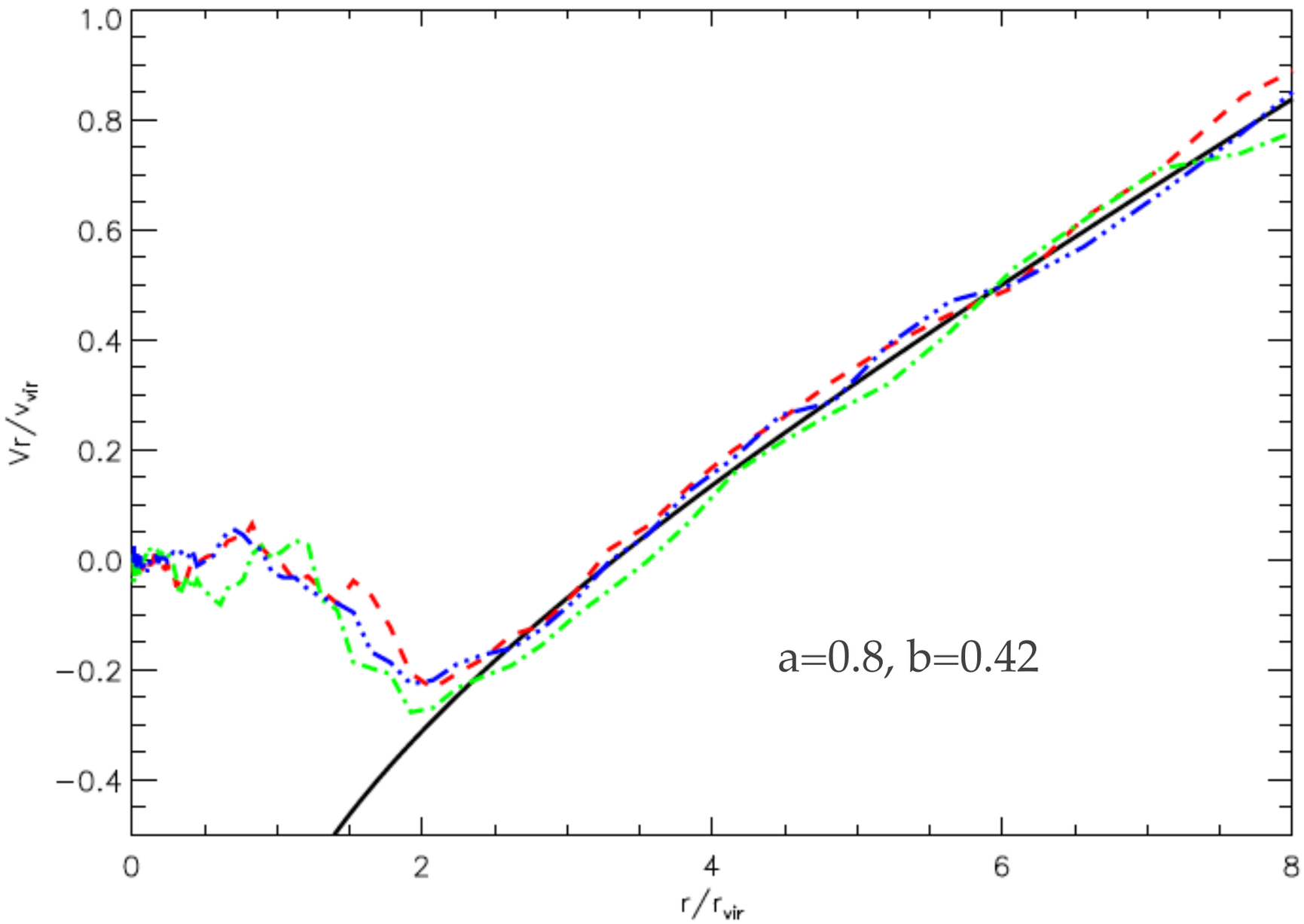
- The infall velocities of satellite galaxies located at (2-4) times the virial radii from the galaxy clusters can be used to determine the mass of galaxy clusters (Falco et al. 2014)

$$\overline{v}_{\rm r}(r, M_{\rm v}) = H\, r + \overline{v}_{\rm p}(r, M_{\rm v})\,,$$

- The peculiar velocity profile in the radial direction has been found by Falco et al. (2014) as

$$\overline{v}_{\rm p}(r) \approx -v_0 \left(\frac{r}{r_{\rm v}}\right)^{-b} \quad \text{with } v_0 = a\, V_{\rm v}$$

Radial Velocity Profiles



Falco et al. 2014, MNRAS, 442,1887

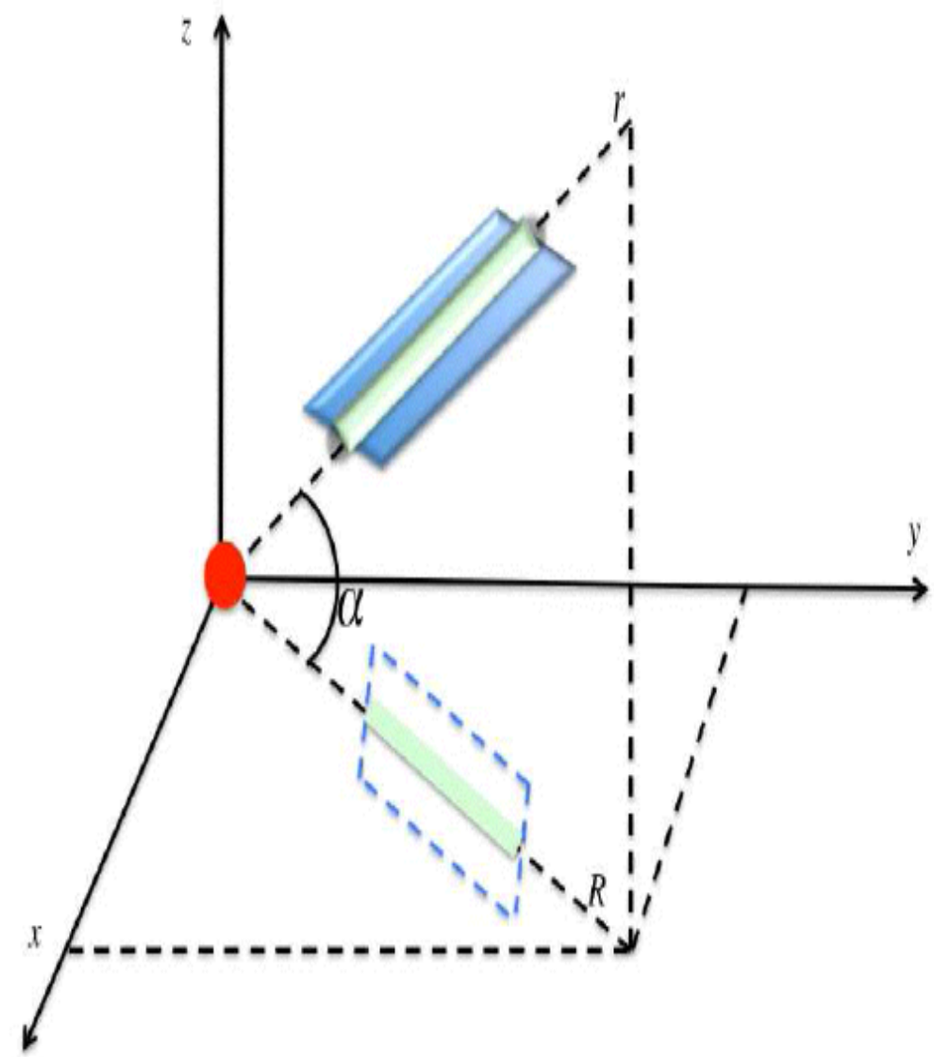
Cosmic Web Environment

$$R = \cos\alpha\, r$$

$$v_{\rm los}(R) = \sin\alpha\, v_{\rm r}(r)$$

$$v_{\rm los}(R,\alpha,M_{\rm v}) = \sin\alpha\left[H\,\frac{R}{\cos\alpha} + v_{\rm p}\left(\frac{R}{\cos\alpha}, M_{\rm v}\right)\right].$$

$$v_{\rm los}(R,\alpha,M_{\rm v}) = \sin\alpha\left[H\,\frac{R}{\cos\alpha} - a\,V_{\rm v}\left(\frac{R}{\cos\alpha\, r_{\rm v}}\right)^{-b}\right].$$



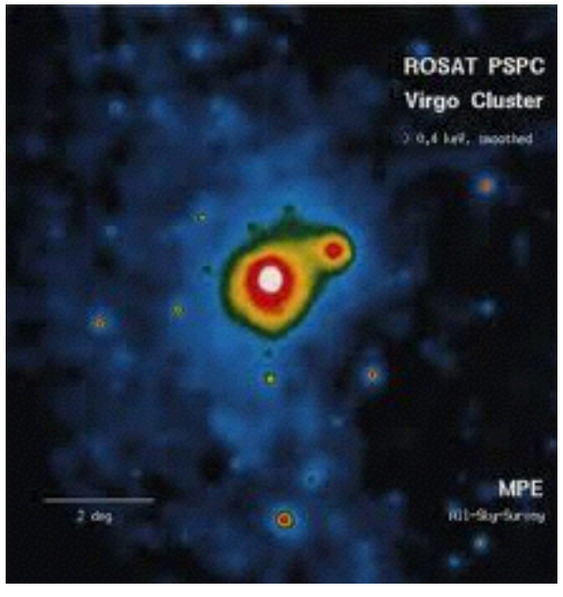
Falco et al. 2014, MNRAS, 442,1887

Anisotropic Merging in the Cosmic Web

- Galaxies merge into the clusters preferentially along the cosmic filaments and sheets.
- The principal directions of the velocity shear field have been found to trace the anisotropic merging very well (Libeskind et al. 2013, 2014a,2014b,2014c)
- The spatial positions and velocity vectors of satellite galaxies are expected to align with the principal axes of the local velocity shears (e.g., Lee, Rey & Kim 2014a)

Virgo Cluster as a Target

- proximity
  - 16.5 Mpc away
- not completely relaxed
  - presence of subgroups
- triaxial shapes
  - elongated along LoS (e.g., Mei et al. 2007)
- located in the filamentary environment
  - the Local Supercluster (Tully 1982)



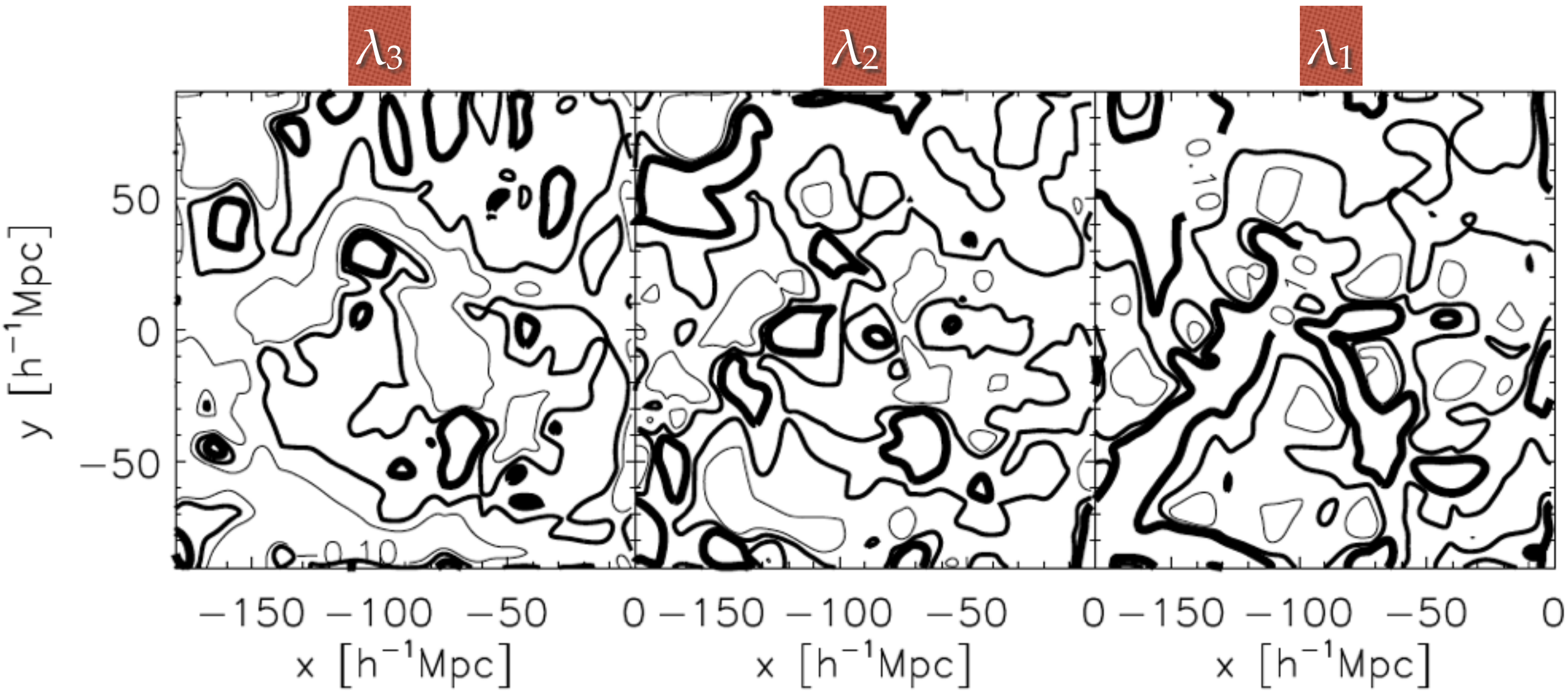
Reconstruction of the Velocity Shear Field

- Construct the velocity shear field in the 180^3 $(\mathrm{Mpc}/h)^3$ sub volume consisting of 256^3 grids
  - by using the velocity field reconstructed by Wang et al. (2012) from the Sloan Digital Sky Survey,

$$\Sigma_{ij} = -\frac{1}{2H_0}\left(\partial_j v_i + \partial_i v_j\right) ,$$

$$\tilde{\Sigma}_{ij} = -\frac{1}{2H_0}\left(k_j \tilde{v}_i + k_i \tilde{v}_j\right) \exp\left(-\frac{R_f \tilde{v}^2}{2}\right) .$$

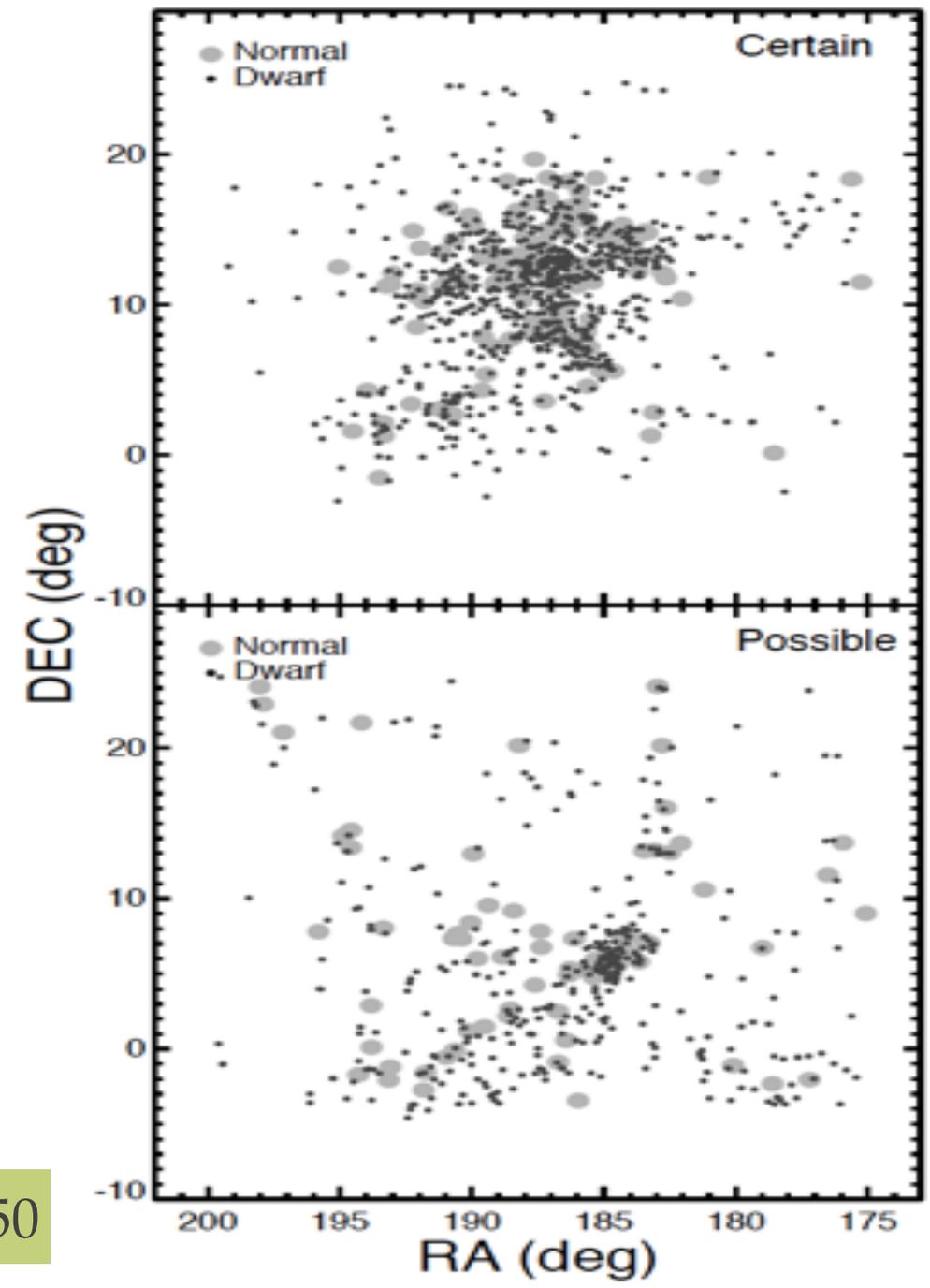
  - where R_f is the filtering radius.



Lee, Rey & Kim 2014, arXiv:1406.5250

Extended Virgo Cluster Catalog

- Kim et al. (2014, submitted to ApJS) constructed the EVCC
  - a total 1589 galaxies
  - m_r<17.77 [mag]
  - spectroscopic information from the SDSS DR7 and NED
  - within 3.5 times virial radius from the Virgo cluster.



Lee, Rey & Kim 2014a, arXiv:1406.5250

Centrals vs. Satellite

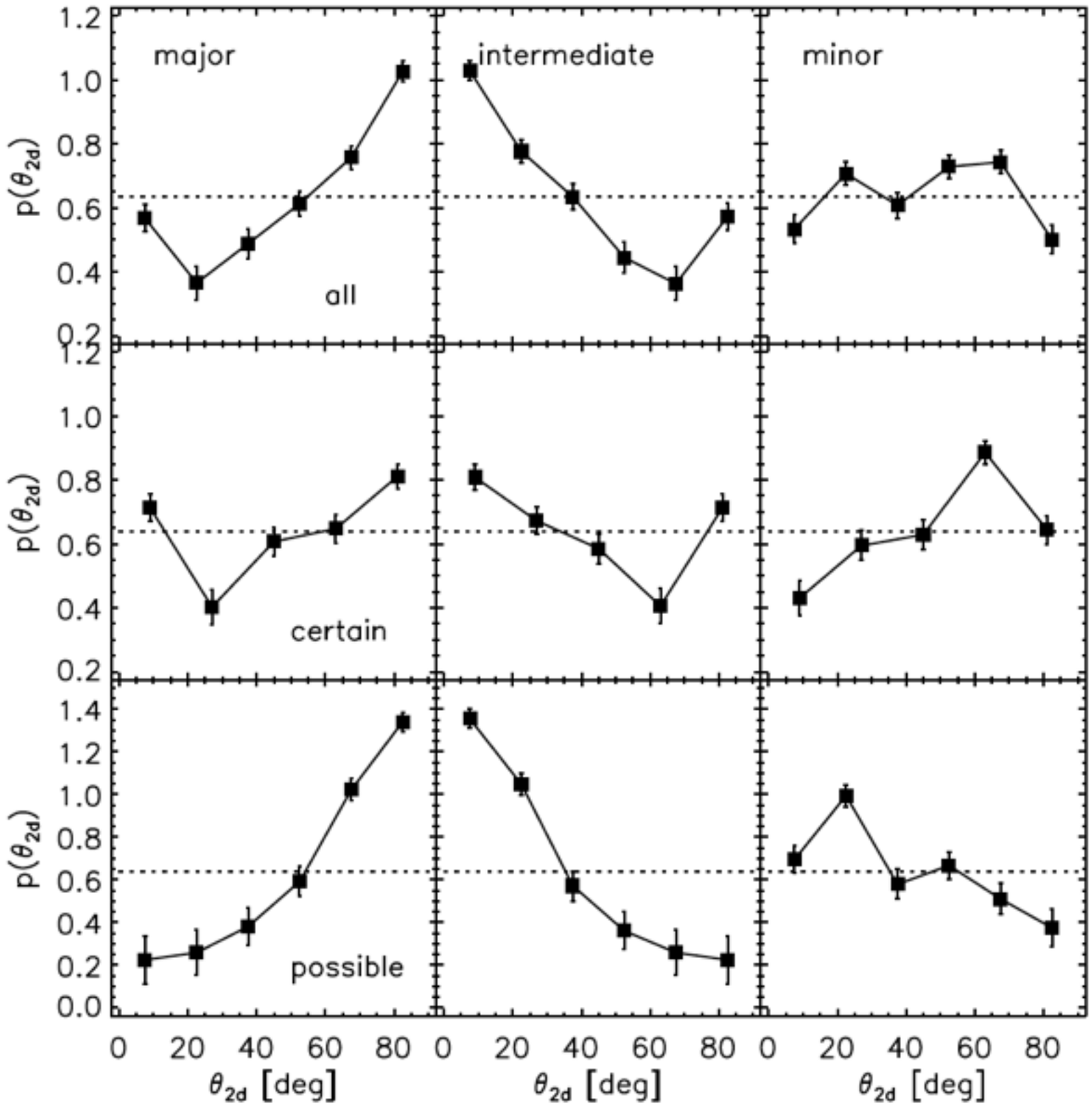
- Central galaxies (a total of 1028)
  - members of the Virgo cluster
  - gravitational bound, located within the virial radius
  - the magnitudes of their heliocentric radial velocities less than a given threshold (Praton & Schneider 1994)

- Satellite galaxies (a total of 561)
  - possible members of the Virgo cluster
  - still merging located beyond the virial radius
  - the magnitudes of their heliocentric radial velocities higher than a given threshold (Praton & Schneider 1994)

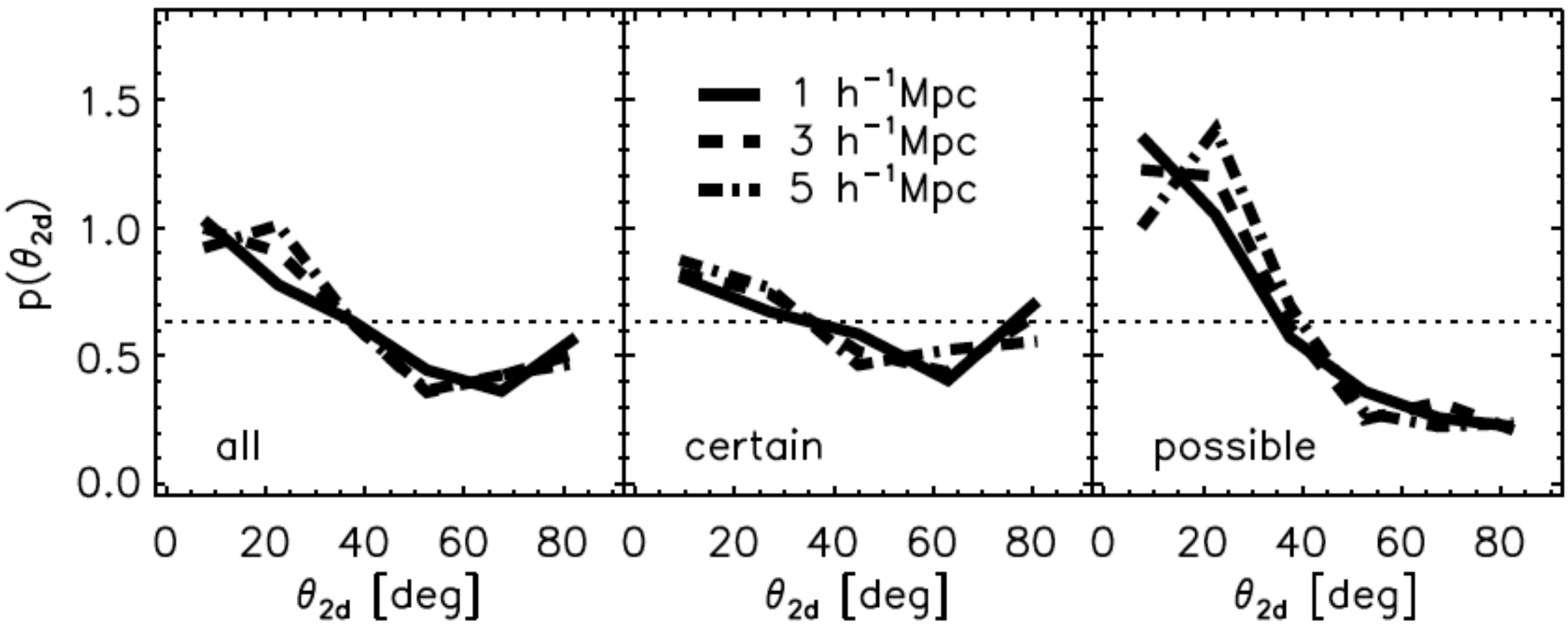
Alignments of the Virgo Satellites with the Velocity Shear

- The minor principal axis of the velocity shear field is found to be almost perfectly aligned with the line of sight direction.
  - The angles of the major, intermediate and minor principal axes with the LoS are 94.7, 98.7, 9.9 in unit of degree, respectively.

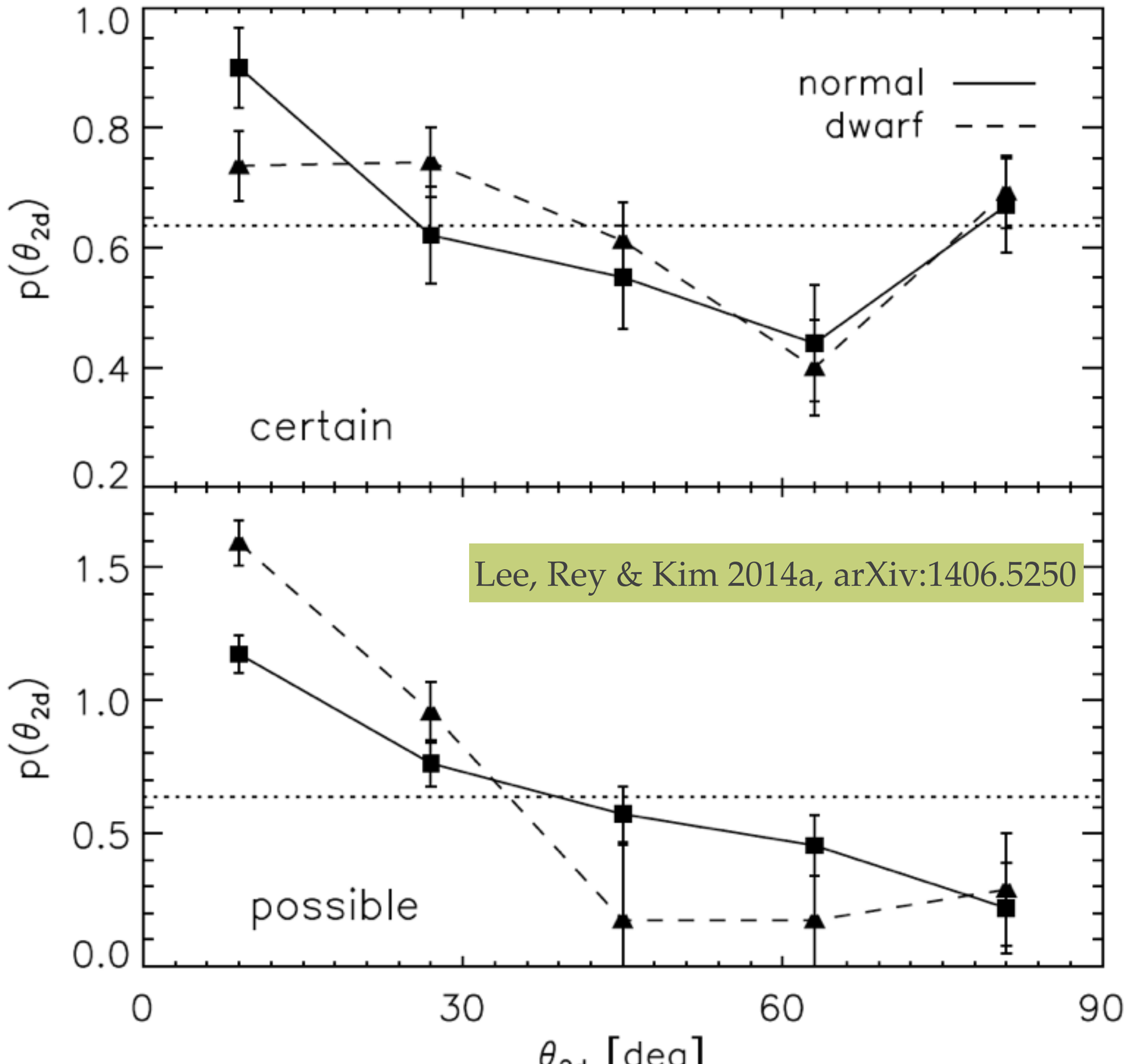
- Measuring the alignments between the projected positions of the Virgo satellites and principal axes of the local velocity shear tensor in the plane of the sky



Lee, Rey & Kim 2014a, arXiv:1406.5250



Lee, Rey & Kim 2014a, arXiv:1406.5250


normal
dwarf
certain
possible
Lee, Rey & Kim 2014a, arXiv:1406.5250
p(θ2d)
p(θ2d)
1.0
0.8
0.6
0.4
0.2
1.5
1.0
0.5
0.0
0
30
60
90
θ2d [deg]

Interpretation

- The giant satellites merge into the Virgo cluster along the filament in the direction of the minor principal axis of the local velocity shear.
- The dwarf satellites merge into the Virgo cluster along the sheet spanned by the minor and intermediate principal axes.
- The 2D project diminishes the strength of the alignment of the giant satellites
  - since the minor principal axis of the local velocity shear is almost perfectly aligned with the line of sight direction.
  - But, the intermediate principal axis of the local velocity shear is almost perfectly lying in the plane of the sky, so that the alignment of the dwarf satellites is not diminished.

Follow-up Work

- From the giant satellites located in (2-4)r_{vir} from the Virgo cluster,
  - determining H_0 and M_{vir} of the Virgo cluster with the help of the GIK method
    - as the value of α has been determined
  - understanding how the galaxies are distributed in the environment surrounding the Virgo cluster
    - difference between the giants and the dwarfs
  - testing modified gravity models which
    - requires a formula for the radial velocity profiles

Summary and Future Works

- The velocity shear field in the local universe was reconstructed.
- The projected principal axes of the local velocity shear at the Virgo cluster are found to be aligned with the projected positions of the Virgo satellites.
- It will allow us to determine the mass of the Virgo cluster without assuming hydrostatic equilibrium as well as the Hubble constant independently.
- Comparison with the results from modified gravity theory is on going.